

ACCURATE REALIZATION OF GPS VERTICAL GLOBAL REFERENCE FRAME

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Annual Report

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1- Introduction

The few mm/yr level accuracy of radial global velocity estimates with the Global Positioning System (GPS) is at least an order of magnitude poorer than the accuracy of horizontal global motions. An improvement in the accuracy of radial global velocities would have a very positive impact on a number of geophysical studies of current general interest such as global sea-level and climate change, coastal hazards, glacial isostatic adjustment, atmospheric and oceanic loading, glaciology and ice mass variability, tectonic deformation and volcanic inflation, and geoid variability.

The goal of this project is to improve our current understanding of GPS error sources associated with estimates of radial velocities at global scales. GPS error sources relevant to this project can be classified in two broad categories: (1) those related to the analysis of the GPS phase observable, and (2) those related to the combination of the positions and velocities of a set of globally distributed stations as determined from the analysis of GPS data. Important aspects in the first category include the effect on vertical rate estimates due to standard analysis choices, such as orbit modeling, network geometry, ambiguity resolution, as well as errors in models (or simply the lack of models) for clocks, multipath, phase-center variations, atmosphere, and solid-Earth tides. The second category includes the possible methods of combining and defining terrestrial reference frames for determining vertical velocities in a global scale. The latter has been the subject of our research activities during this reporting period.

2- Research Activities

We have undertaken one of the key proposed research activities: a sensitivity study to investigate the effects of data analysis choices on the determination of the vertical coordinate of site position and its time variation, which we describe in this section.

We have used the daily estimates of global station positions and covariance matrices spanning about seven years generated by our group at the Smithsonian Astrophysical Observatory (SAO), and the GLOBK software package (*Herring, 2003*) to test various solution combinations and procedures. SAO performs a standard data processing-combination scheme, whereby estimates of global velocities are obtained in a multi-step process (e.g., *Feigl et al., 1993; Bennett et al., 2002*). This process involves (1) analyze the GPS phase observables to produce daily estimates of position (and their covariance matrix), (2) accumulate and combine the daily solutions to obtain velocity estimates, and (3) select a set of sites to define a reference frame.

During this reporting period we have concentrated our efforts on the effects of steps (2) and (3) above and, using GLOBK, have performed the following research tasks: (A) perform a painstaking data editing, (B) combine daily solutions in various manners, and (C) realize reference frames in various manners. The data set used for this research is the daily SAO solutions for about 500 regional and 100 globally distributed sites (Figure 1) obtained with the GAMIT (*King and Bock, 2003*) software package and the SOPAC products (*Bennett, 2002*).

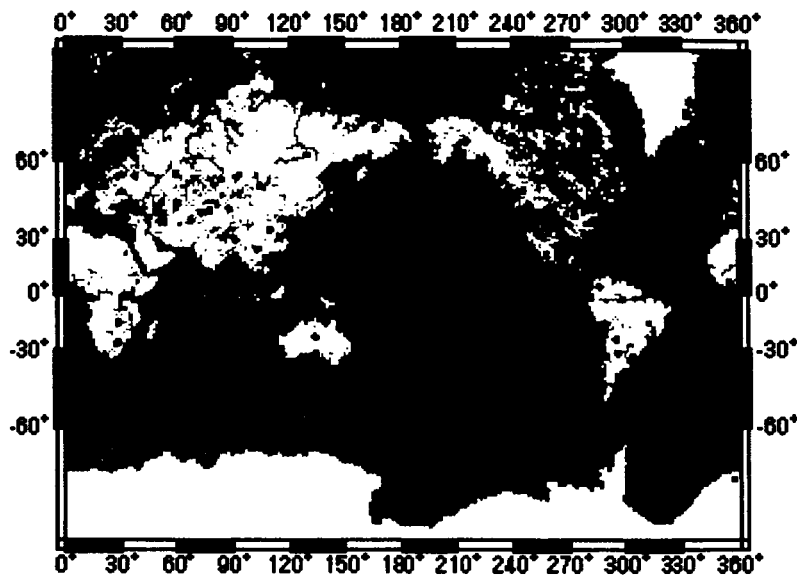


Figure 1: Geographical distribution of sites in the SAO database used in this study.

3- Findings

- (1) We have found that after a few (typically two) iterations of careful editing of the time series of site position estimates for data outliers and jumps, the latter due to known effects such as antenna and antenna radome changes and also unknown effects, the estimates of global radial velocities becomes quite insensitive (at the 0.1 mm/yr level on average, 95% differences <0.3 mm/yr) to subsequent editing refinements (Figure 2). This is important because data editing can be a rather subjective process.
- (2) We have found that estimates of radial velocities are very sensitive (at the 0.5 mm/yr average, but differences up to 8 mm/yr are also possible) to the strategy used to combine daily solution files into an accumulated solution. This finding is quite puzzling and, should it hold, it would imply that radial velocity estimates would depend in large part on the strategy adopted to generate a velocity field, not a very comfortable situation indeed. We are investigating possible reasons for this sensitivity of radial velocity estimates to changes in the approach used. One possibility is the (lack of) orbital information to align independent solutions. In our approach, we combine two independent, loosely constrained velocity solutions, one regional and one global, into a single global velocity solution. Although this approach is statistically sound, and it is common practice, it may not be very accurate. In particular, it is common practice in producing GLOBK daily solution files to discard GPS orbital parameters after combination to save considerable storage space. When this is done, orbital constraints are supposed to be maintained through the site coordinates and Earth orientation parameter estimates and covariances. However, (unexpected) inconsistencies might arise if different solutions that have different site distributions and whose orbital information has been previously discarded are combined. We are currently investigating this specific possibility.

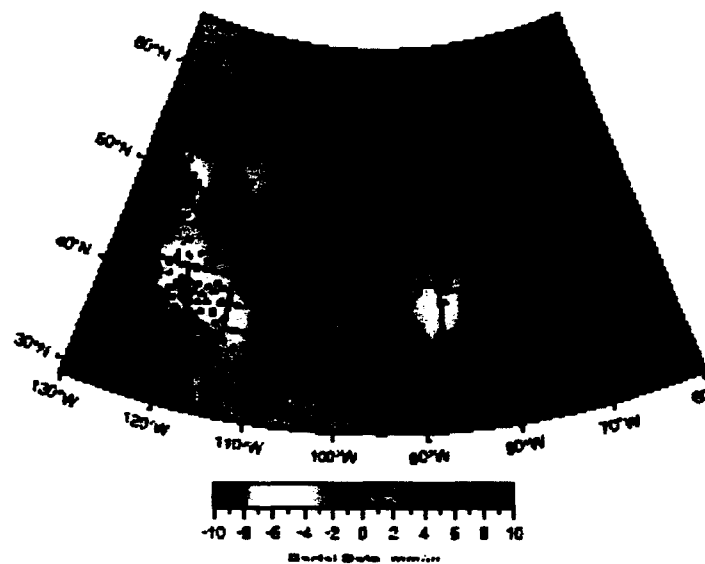


Figure 2: Preliminary radial velocity field for North America after data editing.

- (3) We have found that estimates of radial velocities are insensitive (at the 0.1 mm/yr level) to significant changes in the geographical distribution and the total number of stations used to define a global reference frame (Figure 3). This finding contradicts our intuition and past experience with estimating horizontal velocities from regional networks, which are quite sensitive to site selection. We are currently investigating possible reasons for this lack of sensitivity of radial velocity estimates to changes in site distribution. In particular, we are investigating the dependence of this (lack of) sensitivity to a priori values of site position and velocities. Heretofore, we have been using our own set of internally best a priori values, our best estimates after several data editing and successfully converging iterations. Our a priori values are similar to those from the IGB 2000 (or IGB00 for short), a new terrestrial reference frame based on GPS observations designed to consistent with the International Terrestrial Reference Frame of 2000 (or ITRF00), the latest frame realization of the Internal Terrestrial Reference System. We are currently exploring the sensitivity of radial velocity estimates to changes in the a priori values of changing sets of stations that are used to define a global reference frame.

4- Further research

During the next period of performance, we will further investigate points (2) and (3) as described above as well as investigate the impact on radial velocity estimates of the errors in the theoretical models used (or the lack of models) and the standard choices made during the analysis of the GPS phase observables to produce daily global solutions, the starting point of the research we have performed during this reporting period.

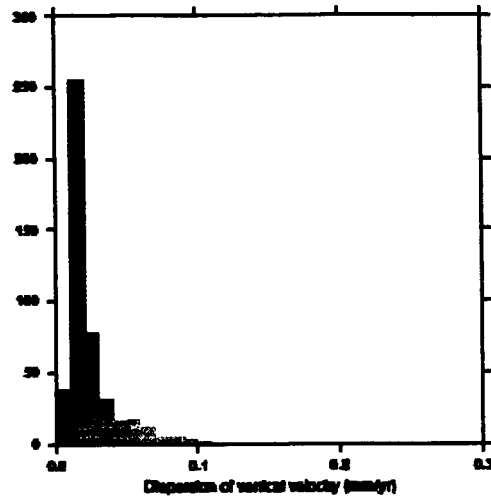


Figure 3: Dispersion of radial velocity estimates of a total of 450 sites in North America (red) and global (red) using 18 different combinations of 40 sites to define a terrestrial reference frame. Repeatability is better than 0.1 mm/yr for 99% of the sites.

References:

Bennett, R.A., J.L. Davis, B.P. Wernicke, and J.E. Normandeau, Space geodetic measurements of plate boundary deformation in the western U.S. Cordillera, in *Plate Boundary Zones*, e.d. Stein, S.A., J.T. Freymueller, AGU Geodynamics Series, Vol 30, 27-55, 2002.

Feigl, K. L., D. C. Agnew, Y. Bock, D. Dong, A. Donnellan, B. H. Hager, T. A. Herring, D. D. Jackson, T. H. Jordan, R. W. King, S. Larsen, K. M. Larson, M. H. Murray, Z. Shen, F. H. Webb, Space geodetic measurement of crustal deformation in central and southern California, 1984 - 1992, *J. Geophys. Res.*, 98(B12), 21677-21712, 10.1029/93JB02405, 1993.

Herring, GLOBK Global Kalman filter VLBI and GPS analysis program, version 10.1, November 2003.

King and Bock, Documentation for the GAMIT GPS analysis software, release 10.1, November 2003.